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THE EFFECT OF VARYING HUMIDITIES UPON SOME PHYSICAL PROPERTIES OF PAPER

by

I. PHILIP SILVERSTEIN

A Thesis Submitted for the Degree
of
Chemical Engineer

The University of Wisconsin
1916

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O L Kowalke 6/15/16.

FOREWORD

This work was done at the Forest Products Laboratory of the Forest Service, United States Department of Agriculture, and all rights of publication are reserved by the Laboratory.

The investigation was suggested by Dr. Otto Kress, Chief of the Section of Pulp and Paper, and was carried out under his direction.

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Introduction

Countless numbers of disputes have taken place between paper makers and paper users because of the seeming impossibility of making paper exactly alike on different occasions. Papers which have been made in apparently the same way, of the same furnish and under seemingly identical conditions vary widely in their physical tests. Very often paper which gives one set of tests at the mill will give a different set of tests at the destination.

Paper is essentially a net work of interwoven cellular fibres, which may or may not be sized, colored, or loaded. By sizing is meant the coating of the individual fibres by rosin, gelatine or other substances, so as to render the fibre water resistant to a greater or less degree depending upon the extent of sizing. By loading is meant the addition of mineral filler such as china clay, asbestos, pearl hardening, etc. for the purpose of increasing weight, finish, opacity, etc.

Paper Testing

Paper is bought on the basis of weight and strength. For newspaper, the basis is the ream of five hundred sheets measuring 24" x 36", weighing 32 pounds, and having a bursting strength of about 11.5 pounds per square inch. If the paper is thicker and, therefore, heavier, the printer must buy more

pounds for the same superficial area. If the paper is strong then he can use a lighter weight sheet and reduce the number of pounds to be paid for. The same holds true for wrapping papers. Between two papers of equal strength and of different ream weight, the choice is always for the lighter one because it costs less. Specifications for papers are becoming more rigid as to the ream weight and strength requirements and an entire shipment may be rejected because of a variation in one of these qualities.

The physical tests employed in arriving at a basis of comparison of the quality of papers are:

1. Ream weight
2. Thickness
3. Resistance to bursting; points per pound
4. Tensile strength; breaking length
5. Stretch
6. Resistance to folding

1. By "ream weight" is meant the weight in pounds of a ream of 480 or 500 sheets (as specified), the superficial area depending on the kind of paper. It is obtained by cutting a definite fraction of a ream from a sheet of paper by means of a metal template and weighing it on a scale calibrated to give the ream weight directly.

2. The thickness is measured by inserting the sheet between the jaws of a pair of spring or screw calipers

graduated to read to one thousandth of an inch. Some machines are graduated to read to one ten thousandth of an inch.

3. The resistance to bursting is measured on any one of a number of instruments, the Mullen tester being used at the Forest Products Laboratory. The paper is clamped over one end of a cylinder filled with glycerin, a flexible rubber diaphragm separating the paper from the liquid. By turning a hand wheel, the glycerin is compressed forcing the rubber diaphragm against a circular section of the paper which measures exactly one square inch. A gage records the pressure required to burst thru this one square inch of paper.

The resistance to bursting varies with the kind of paper and with the thickness of the sheet, a 50-pound paper, i.e., a paper weighing 50 pounds to the ream being stronger than a 30-pound paper, other conditions being equal. For comparative values of the bursting strength of papers of the same kind but of different ream weights, an expression called "Points per pound" is in use. It is obtained by dividing the bursting strength by the ream weight giving the bursting strength per pound of ream weight.

Another expression which is sometimes used is the "bursting strength per one thousandth of an inch in thickness". It is obtained by dividing the bursting strength of the sheet by its thickness and gives an expression independent of the thickness or ream weight.

4. The tensile strength is measured on one of a number of tension instruments, the Schopper machine being used at the Laboratory. Strips of paper 15 millimeters

(approximately five-eighths inch) wide are cut in a special cutter which insures strips of uniform width. The strip of paper is clamped between two jaws 180 millimeters (about seven inches) or less apart in a vertical position. The lower jaw is connected to a piston which may be operated by a hand wheel, motor or hydraulic pressure, while the upper jaw is pivoted about a shoulder to a lever arm which may or may not be weighted with a kilogram weight, depending on the strength of paper tested. When the machine is at rest the lever arm with its kilogram weight hangs vertically and the pointer attached to the center of the arm registers zero on a graduated arc. As the lower jaw is pulled down by the piston, the force is transmitted through the strip of paper to the upper jaw with its weighted arm and the weight moves outward and upward along an arc offering an increasing resistance to the pulling force. At the limit of strength the strip of paper breaks, releasing the pull on the lever arm which is held in place by a set of dogs catching in a rack on the graduated arc. The pointer shows the pull in kilograms at the time of breaking.

The tensile strength varies with the kind of paper, the width of the strip and the thickness. For paper of any one kind and strips of the same width, the tensile strength varies with the thickness. A numerical expression for the tensile strength of paper which depends solely upon the nature of the paper is called the "Breaking Length".

If BL = breaking length in meters

S = length of strips in meters

W = weight of strip in grams

K = tensile strength in kilograms

Then $BL = \frac{K \times S \times 1000}{W}$

The breaking length is thus the length of a strip of paper which is equal in weight to the tensile strength, or expressed in another way, the breaking length is the length of a strip of paper which, if suspended from a support, will break at the point of support due to its own weight. This expression is independent of the width of the strip or the thickness, and gives a value by which the papers of the same class but of different ream weights may be compared.

5. The stretch of paper is obtained simultaneously with the tensile strength. The lower jaw of the Schopper machine carries a rack which actuates a pointer along a graduated arc and shows the distance between the jaws. As the paper is stressed and it begins to stretch, the distance between the jaws is increased and the pointer moves outward. When the paper breaks the pointer remains stationary showing the stretch or percentage elongation at the time of breaking.

6. The resistance to folding is obtained on a folding machine by placing a strip of the same width as used for the tensile and stretch tests between two jaws about 3-1/2 inches apart and subjecting it to a constant tension of

one kilogram. By means of a motor or hand wheel a reciprocating rod folds the strip back and forth at the same place until the strip is so weakened that it is pulled apart by the constant tension of one kilogram. A recording dial which is disengaged when the paper breaks, automatically records the number of double folds.

Machine made paper is almost always stronger in the direction in which the machine runs than in the "across" machine direction. The stretch also varies, the stretch in the machine direction always being less than that in the cross direction. The resistance to folding is usually greater along the machine direction than in the cross direction. To get average results, at least five tests are made for bursting strength, five tests for tensile strength and stretch along the machine direction and five tests across the machine direction and these results averaged. For folding the average of three tests in each direction is taken.

Influence of Humidity on Strength

Since the individual fibres of a sheet of paper are hygroscopic, the whole sheet consisting so largely of fibrous material naturally possesses this quality, though to a lesser degree than the individual fibres. It is a common observation that on humid days a sheet of paper is

more limp, stretches more and is less resistant to tearing and bursting than on dry days. The humidity of the atmosphere varies from 30 per cent in cold dry weather to almost 100 per cent in foggy or in hot moist weather. Indoors, the humidity ranges are not so wide but in winter on a cold dry day the humidity in a steam heated room often falls to 20 per cent and in summer with all the windows open the humidity indoors may be almost as high as that outdoors.

Excepting the data given by Professor Wilhelm Herzberg in his treatise on "Papierprüfung" very little information can be found in the literature on the effect of varying humidities on the physical properties of paper. The following table taken from the third edition of Professor Herzberg's book, shows the results on the breaking length and stretch of a "good grade of writing paper made of rags, sized with rosin and tested under varying conditions of humidity".

It is evident that the atmospheric moisture does have a great effect on the strength and stretch of paper. As the humidity falls, the breaking length is increased and the stretch decreased. G. Dalén also states that for relative

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Relative humidity of air	Moisture contained in the paper	Breaking Strength		
		Machine direction	Across the machine direction	Average
Per cent	Per cent	Kgs.	Kgs.	Kgs.
100	15.2	2.34	1.75	2.05
90	11.3	3.41	2.30	2.86
80	6.5	5.57	4.03	4.30
70	6.2	5.74	4.14	4.94
60	5.5	6.15	4.49	5.32
50	4.6	6.59	4.71	5.65
40	3.8	6.74	4.93	5.84
30	2.3	7.21	5.05	6.13

It is evident that the atmospheric moisture does have a great effect on the strength and stretch of paper. As the humidity falls, the breaking length is increased and the stretch decreased. G. Dalén also states that for relative

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ch		Breaking Length		
s the hine ction	Average	Machine direction	Across the machine direction	Average
cent	Per cent	Km.	Km.	Km.
3	4.8	1.68	1.23	1.46
.8	4.3	2.40	1.64	2.02
.7	3.6	4.06	3.00	3.53
.3	3.2	4.25	3.09	3.67
.9	2.9	4.50	3.33	3.92
4	2.6	4.76	3.43	4.20
3	2.5	4.91	3.61	4.26
.6	2.1	5.39	3.80	4.60

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It is evident that the atmospheric moisture does have a great effect on the strength and stretch of paper. As the humidity falls, the breaking length is increased and the stretch decreased. G. Dalén also states that for relative humidities between 0 per cent and 80 per cent paper expands in direct proportion to the amount of moisture present. But when the relative humidity is between 80 per cent and 100 per cent, the expansion is somewhat over this proportion.

As a result of the investigations made at the testing laboratories in Germany, all papers for Government use are tested at the Royal Testing Laboratories at Gros-Lichterfelde under a constant relative humidity of 65 per cent.

G. Dalén after many experiments on the effect of varying humidities on the breaking length and stretch of papers, has constructed a table of factors by which the results for breaking length and stretch obtained at any relative humidity are to be multiplied to obtain the correct result for 65 per cent relative humidity. This table of factors has been published in Herzberg's book on page 18.

Object and Scope of the Investigation

It has long been accepted as fact that for some properties of paper, doubling the thickness would more than double the strength. For example, it is thought that with a 20-pound and a 40-pound paper of the same furnish and made under the same conditions, the resistance to folding of the 40-pound sheet will be more than twice that of the 20-pound sheet.

It was, therefore, decided to extend the investigation to include the effect of varying humidities on the physical properties of individual papers and to correlate these results so as to show how they are affected by varying the thickness.

To get comparable results it was necessary to get samples of papers made of the same stock furnish, under the same conditions but of different ream weights, and to make complete tests at as many different humidities as the apparatus would permit.

Apparatus

The constant humidity room at the Forest Products Laboratory is a double-walled room 8'-2" x 9'-5½" x 7'-6" high, fitted with a Carrier Engineering Company constant temperature and constant humidity apparatus. Plate I represents a diagrammatic sketch of the apparatus which consists essentially of a galvanized iron conduit "A" in one corner of the room and reaching from the floor through the roof where it is connected with a motor driven fan "B". The outlet from "B" leads through heating coils "C" into flue "D" and back into the room. At the bottom of the conduit "A" is a water box "E" from which the pump "F" draws its supply of water and pumps it to the sprays "G", the water dropping down into the tank "E". Above the sprays are a series of baffle plates "H". An air compressor "J" delivers compressed air to the tank "K". "L" is the humidity regulator, "M" is a thermostat, while "N_1" and "N_2"

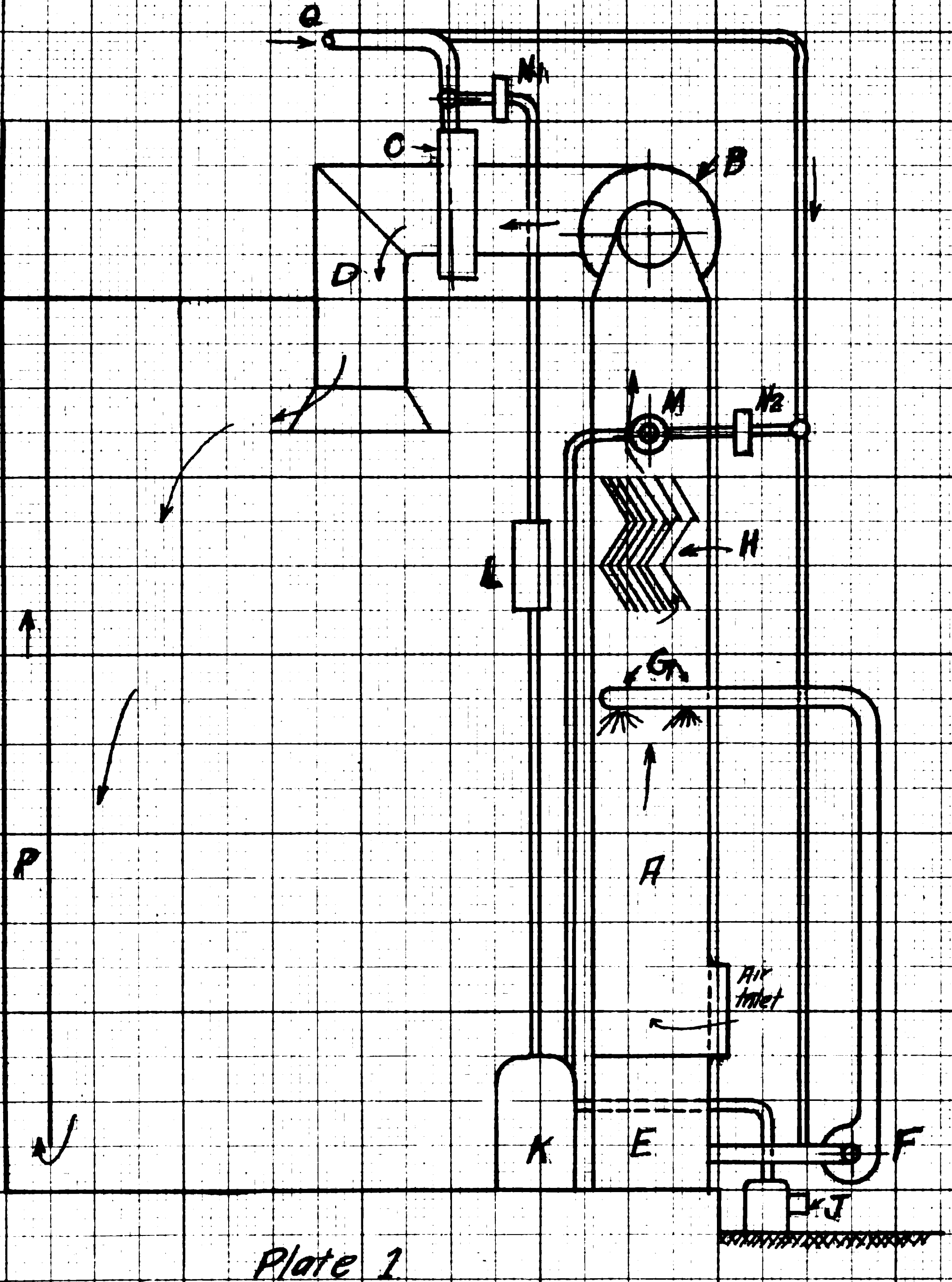

Plate 1
Diagrammatic sketch of
Constant Humidity Apparatus

are diaphragm valves. "P" is an air outlet duct. "Q" is a steam supply line in which the steam is reduced to a pressure of 5 pounds per square inch by means of a reducing valve.

During operation, the pump "F", sprays "G", compressor "J" and fan "B" are in constant operation. Air enters the opening in "A" as shown by the arrow, passes up through the sprays "G" and into the baffle plates "H" where the entrained water is removed, then up through fan "B", heater "C", and flue "D" into the room and finally out into the atmosphere through flue "P".

Before explaining the regulation of the temperature and humidity it is best to review some definitions. The "dew point" of air is that temperature at which it is saturated with a given amount of water vapor. If cooled below this temperature, some vapor will condense and dew will deposit. The "dry bulb" temperature is the ordinary temperature in the room as given by an accurately graduated thermometer. The "wet bulb" temperature is that given by a thermometer similar to that used for determining the dry bulb temperature but having the bulb tightly covered with a piece of soft muslin which is thoroughly wetted and over which a current of air is passed. Due to the evaporation of some water from the cloth, the wet bulb temperature is always less than that of the dry bulb except at the dew point, when all three temperatures read alike. The "relative humidity" is the ratio of the amount of water vapor in a given space, to the

weight which the same space will hold when fully saturated at the same temperature and is expressed in per cent. Since vapor pressure depends entirely upon the temperature, relative humidity can be expressed as the ratio of the vapor pressure of the wet bulb temperature to that of the dry bulb temperature.

For a given amount of moisture, the dew point is always the same, because at the dew point temperature only, is the air saturated with that amount of moisture. If now this air is heated,both the dry bulb and wet bulb temperatures rise, the dry bulb more rapidly than the wet bulb because the latter is cooled by the evaporation of water from its muslin jacket. As the air is heated, its capacity for water vapor is increased and, therefore, the relative humidity falls. By taking the difference between the wet and dry bulb thermometers, the relative humidity can be found by consulting a humidity chart or a set of tables.

The above mentioned method of regulation is employed by the apparatus in use. Referring to Plate I, the air as it passes from the baffles "H" is saturated with water vapor, i. e., it is at its dew point. If no heat is added to or taken from the air it will pass through the fan and into the room at the same temperature as that which it had when leaving "H", and the wet and dry bulb thermometers will both register the same temperature, namely that of the dew point. No evaporation can take place from the wet bulb thermometer

because the surrounding air is already saturated and can hold no more moisture.

If now, the humidity regulator "L" is set for say 60 per cent relative humidity, then by means of the diaphragm valve "N_1", steam is admitted to the heating coils and the air heated. As the temperature rises, the capacity of the air for water vapor increases and the relative humidity decreases. At 60 per cent the humidity regulator shuts off the steam from the heating chamber until the humidity in the room rises above that for which it is set when steam is again admitted to the heaters. The actuating mechanism in the humidity regulator is a silk thread which contracts and expands with the amount of moisture present in the room. Through this regulator the compressed air from "K" being at a higher pressure than the steam keeps the diaphragm valve shut. When the percentage humidity rises above that for which the regulator is set, the silk thread expands and shuts off the air pressure and steam is admitted to the heating coils.

For high relative humidities where it is necessary to keep the temperature of the sprays above that of the water from the supply pipes, the thermostat "M" operates the diaphragm valve "N_2" which governs the admission of steam to the spray water as it enters the pump "F".

In order to obtain comparable results for the effect of varying thickness it was necessary to secure samples of paper made from the same stock furnish and under the same conditions of manufacture. Occasionally a mill receives an

order for papers of the same kind but of different ream weights in which case the stock is all prepared in the same way and the ream weights changed as the pulp flows over the paper machine. Samples of paper made in this way were sent in by three mills. Each set of papers was made of the same stock, at the same time and under the same mill conditions, and the papers in each set are as nearly alike in everything except ream weight as it is possible to make them under commercial conditions.

Mill No. 1 sent a set of three papers, samples of 25, 30 and 34-pound paper. The furnish consisted of

30% bleached groundwood
40% balsam sulfite
30% hemlock sulfite
10 lbs. alum, 7 lbs. size
1/16 oz. auramine concentrated
1/16 oz. orange R. O.

Mill No. 2 sent a set of three papers, samples of 25, 40 and 60-pound papers and made of all spruce sulfite pulp. Mill No. 3 sent two sets of papers, both made of all sulfate pulp and called "No. 1 Kraft" by the manufacturer. One set consisted of samples of 25, 30, 40, and 50-pound papers, the other of 30, 40, and 60-pound papers.

Experimental

Before beginning the actual testing it was necessary to determine the length of time required for the paper

to "season", i. e. to reach the desired moisture content.

Herzberg in his "Papierprüfung" states that the 15 millimetre strips should be kept under the desired atmospheric conditions for at least half an hour before testing.

K. Fenchel and K. Cornely*, state that "experiments on the rate of absorption and loss of moisture when pulp was transferred from an atmosphere at 50 per cent humidity to one at 70 per cent and then back again, showed that two hours were sufficient for the establishment of equilibrium with the moister atmosphere but on returning to the drier atmosphere, the original weight was not restored in so short a time." In these experiments the humidity was controlled by blowing the air through $CaCl_2$ solutions or through granulated $CaCl_2$.

To see how long it would take for papers to become saturated under the conditions of the experiment sheets of newspaper, all rag stationary, light and heavy weights of kraft wrapping paper, light and heavy weights of "water finished" wrapping paper and a sheet of unsized aspen soda pulp were suspended from a string across the room and each sheet was weighed approximately every half hour on an analytical balance, until the weight became constant.

Chart No. 2 shows the result when changing from 50 per cent relative humidity to 70 per cent. The curves

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*J. Soc. Chem. In. Vol. 32, No. 23, p. 1103.

show that in two and one-half hours all the papers have practically attained equilibrium. A striking feature of this test is that the heavily sized all rag paper reached a state of constant weight about half an hour before the unsized aspen pulp. The light weight papers also tend to approach equilibrium somewhat sooner than the heavier papers.

The papers for each day's run were hung loosely from a line strung across the room and left to season for at least three hours. The papers were suspended so that the air had free play around them, Each weight of paper was tested for ream weight, thickness, bursting strength, tensile strength, stretch, and folding. The sheet of paper used to find the ream weight was then tested for bursting and for thickness at the burst section. For the other test , strips of paper were tested in both the machine direction and across the machine direction. Each of the results given in the following tables is the result of a number of experiments, the number varying with the conduct of the paper. If the sheet was uniform and the results did not vary greatly, five tests were made for bursting and tensile strength. If, however, the sheet was "wild", then eight or ten tests were made and the results averaged. For folding, the results are the average of three tests in each direction. Each set of papers was tested without interruption on the same day to avoid any possible changes in the relative humidity and all the conditions of testing were kept as nearly constant as possible.

Each set of papers was given a serial number and the papers of each set identified by using the ream weight as a subnumber. For instance, series III, 60, means that the paper belongs to Series III and weighs 60 pounds to the ream of 500 sheets.

The mixed groundwood and sulfite paper from Mill No. 1 was called Series I. The all sulfite paper from Mill No. 2 was called Series II. The set of four weights of kraft paper was called Series III, and the set of three weights of kraft was called Series IV.

An automatically operated wet and dry bulb thermometer or psychrometer was used to find the relative humidity.

The extreme ranges of humidity we were able to get with the cooling water at our command were 41 per cent and 82 per cent, and the humidity regulation was not very satisfactory. The lower curve on Plate II shows the relative humidities as determined with the psychrometer corresponding to the time shown. The wide variation in humidities as shown was later reduced to about 15 per cent. The average humidity was determined by plotting the humidities as shown and taking a percentage humidity which will divide the upper and lower areas equally.

After the series of tests for this investigation had been completed, one of the heating coils was found to leak steam and was removed. The effect of this change was to greatly increase the efficiency of the apparatus by reducing the range through which both the temperature and humidity fluctuate.

Referring back to the description of the apparatus it is seen that when steam is admitted to the heating coils, the temperature rise of the passing air must be very large and the percentage humidity greatly reduced, especially as the room is very small and the highly heated air enters with a rush, the temperature rise being as much as 11 degrees in one minute with a corresponding drop in the relative humidity of nearly 20 per cent. With the modified heating coils, the temperature rise is reduced to about 6 degrees and the relative humidity change reduced to 7 per cent or less. It is thought that by removing still another coil from the heater the temperature and humidity variations can be still further reduced.

Results of the Experiment

The results of the tests under varying humidities are shown in detail in the accompanying tables, and graphically by means of curves. Keeping in mind the poor humidity regulation these results can only be considered as indications, to be verified when the apparatus is in better working condition. However, certain conclusions may be drawn which should be of interest:

1. The value of points per pound increases with the decrease in humidity. The increase for humidities between 40 and 65 per cent is fairly regular but the increase of the relative humidity above 70 per cent causes a large reduction in strength. For example, on the groundwood-sulfite mixture, Series I, taking the strength at 65 per cent relative humidity

as standard, the average variation for the three papers was 8 per cent for the humidity change from 41 per cent to 65 per cent while from 65 per cent to 82 per cent the drop was 21.5 per cent, giving a total variation in strength of almost 30 per cent. On the No. 1 kraft, Series IV., the variation from 44 per cent to 64 per cent relative humidity was 13.7 per cent, while from 64 to 82 per cent the difference in strength was 11.9 per cent, the total variation in strength being nearly 26 per cent.

2. The same results seem to hold for the breaking length. Above 70 to 75 per cent relative humidity the strength falls more rapidly than between 40 per cent to 75 per cent. For the groundwood-sulfite mixture, Series I, again taking the values at 65 per cent as standard, the variation in breaking length between 41 per cent and 65 per cent relative humidities is 10 per cent, while for an increase in humidity from 65 per cent to 82 per cent caused a reduction in the breaking length of 37.2 per cent, a total variation of over 47 per cent. For Series IV, No. 1 kraft, the variation in breaking length for the humidity change from 44 per cent to 64 per cent was 6.5 per cent, while with an increase in humidity from 64 per cent to 82 per cent the drop in breaking length was 19.3 per cent, a total variation of 25.8 per cent.

3. The stretch of the paper increases with increase in relative humidity, the variation being rather more regular than with points per pound and breaking length. For

the groundwood-sulfite mixture, Series I, the stretch increased 22.5 per cent with increase in humidity from 41 per cent to 65 per cent, and 22.8 per cent with increase in humidity from 65 per cent to 82 per cent. For the No. 1 kraft, Series IV, the stretch increased 20.4 per cent with increase in humidity from 44 per cent to 64 per cent, and 19 per cent with increase in humidity from 64 per cent to 82 per cent.

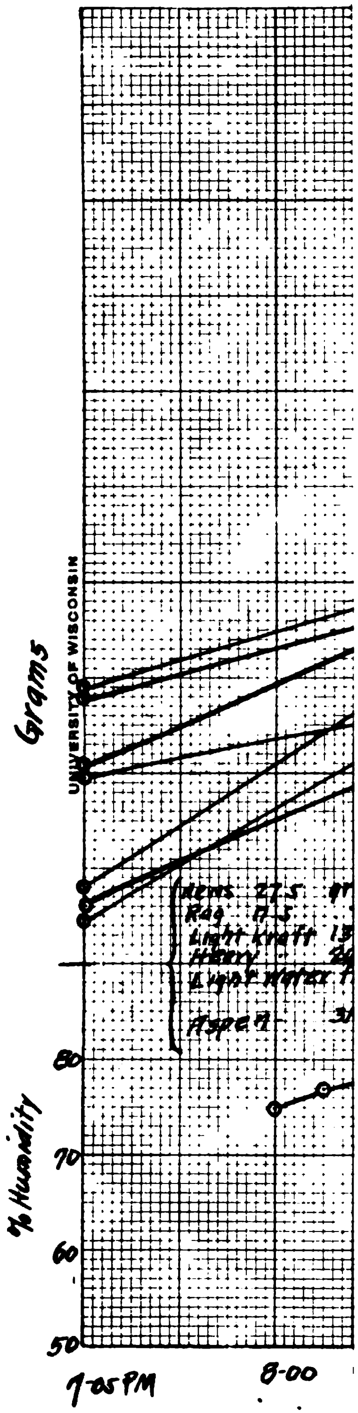
4. The folding properties seem to be affected to a greater degree than any other property. For the groundwood sulfite mixture and the all sulfite papers, the resistance to folding increases tremendously between 55 and 77 per cent relative humidity, a further increase in the moisture content, however, causing the folding strength to break sharply. With the kraft papers, the folding strength increases with the increase in humidity and at the most saturated condition we could get, viz. 82 per cent, the papers were far stronger than at 77 per cent. For the groundwood sulfite paper, Series I, 30, the number of fold increased 130 per cent with a humidity increase from 41 per cent to 77 per cent. For the Series IV, 30, paper the number of folds increased from 348 at 44 per cent relative humidity to 1632 folds at 82 per cent humidity, an increase of 430 per cent.

5. A surprising result is the effect of thickness upon the strength of paper. In only one set of papers, namely Series IV did the heaviest paper prove to be the strongest,

and even here it proved strongest only to bursting and folding, the breaking length throughout the whole range of varying humidities being the lowest of the three papers tested. Usually in the other sets of papers the heaviest paper proved to be the weakest per pound of ream weight in all the properties.

This thesis must be regarded in the nature of a progress report. With better temperature and humidity regulation by the apparatus, it is hoped to obtain results which will be more regular and which will furnish sufficient data to fix a standard temperature and humidity at which papers should be tested for more uniform results than are obtained under present rule of thumb practice.

However, the results obtained are sufficient to show that when paper is bought and sold on strength specifications, the relative humidity at the time of testing should be specified.



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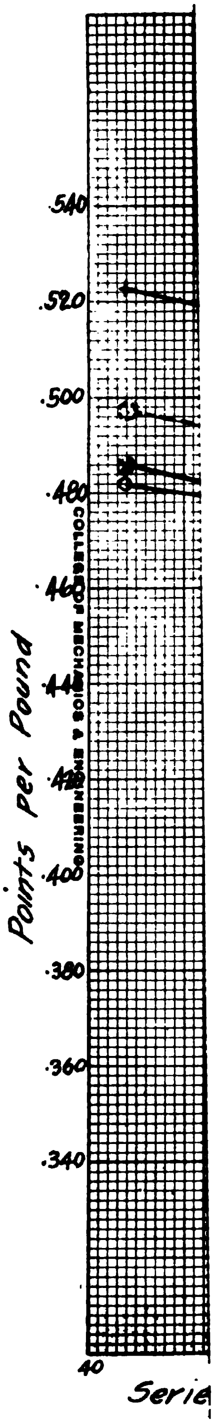
from 50% to 70%


Points per Pound
.540
.520
.500
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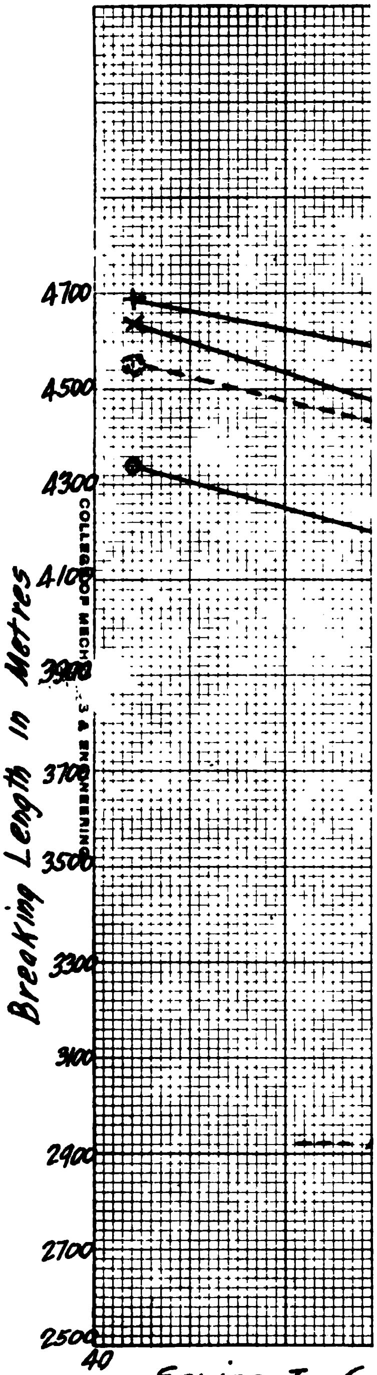
.460
.440
.420
.400
.380
.360
.340
40
Serie
COLLEGE OF MECHANICS & ENGINEERING


Breaking Length in Metres
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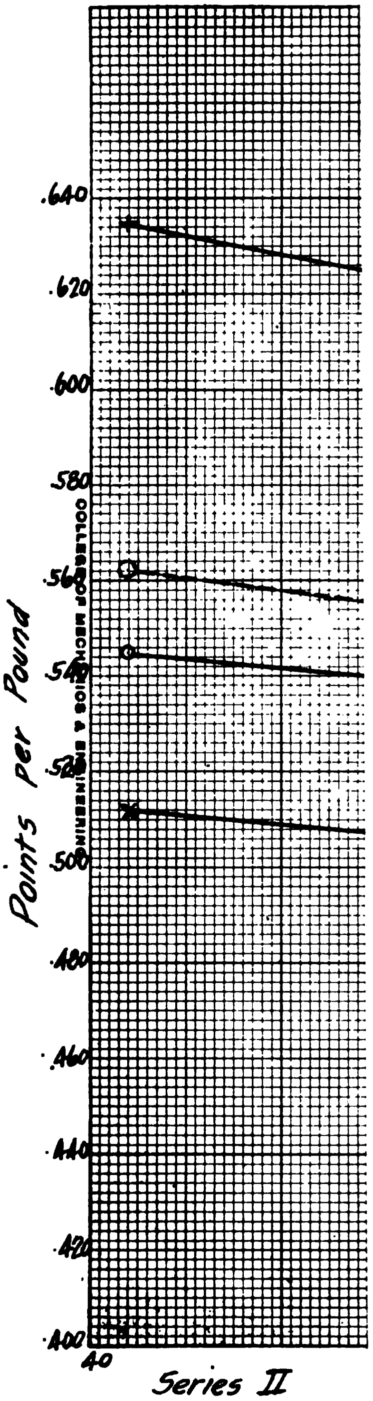
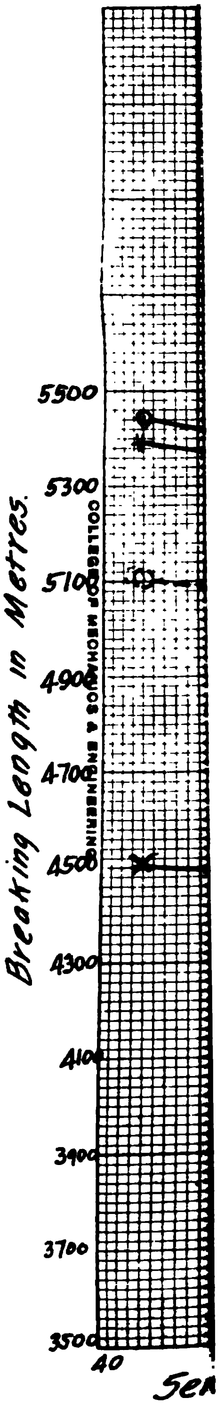
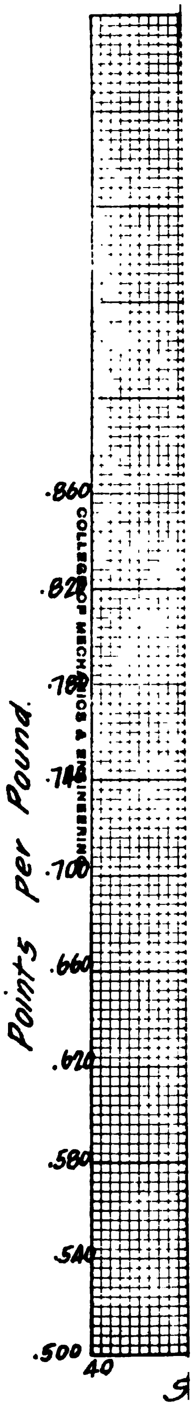
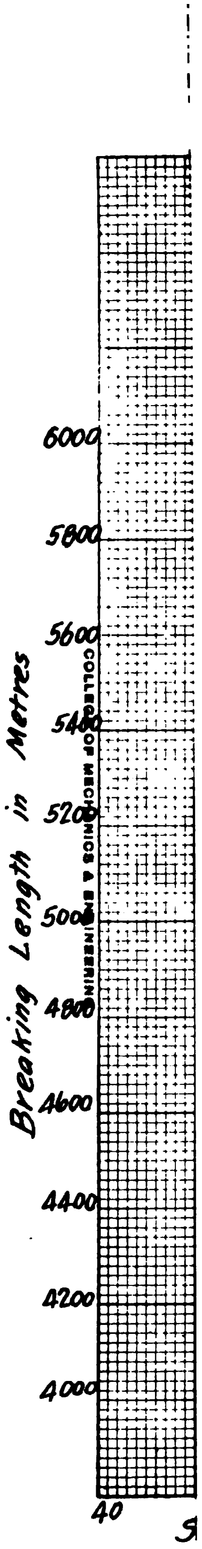
3100
2900
2700
2500
40

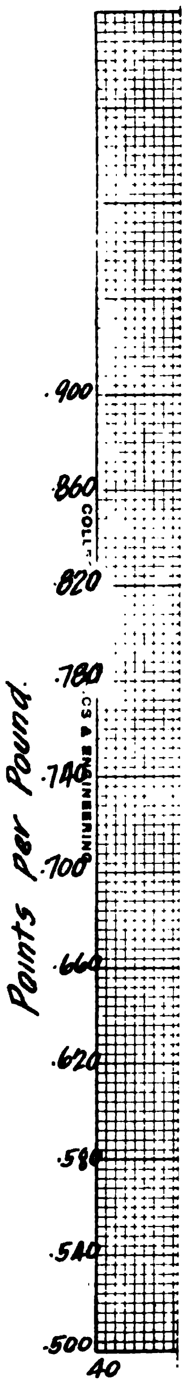
Series I. G

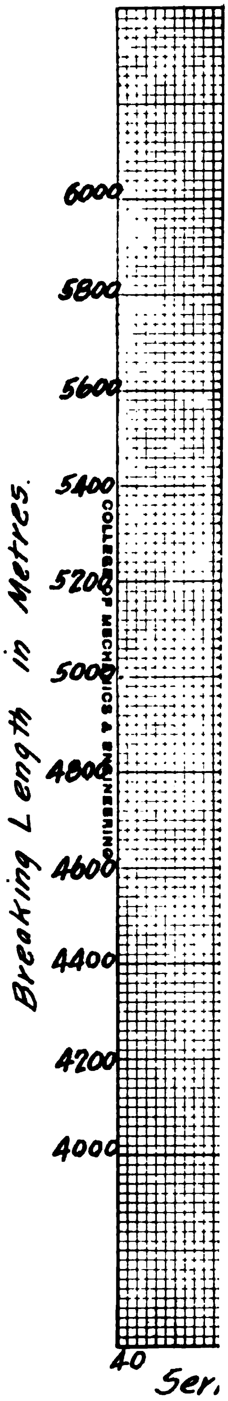

.640
.620
.600
.580
.560
.540
.520
.500
.480
.460
.440
.420
.400
40
Points per Pound
Series II


Breaking Length in Metres.
5500
5300
5100
4900
4700
4500
4300
4100
3900
3700
3500
40
Ser
COLLEGE OF MECHANICS & ENGINEERING


Points per Pound.
.860
.820
.780
.740
.700
.660
.620
.580
.540
.500
40
5
COLLEGE OF MECHANICS & ENGINEERING


Breaking Length in Metres
6000
5800
5600
5400
5200
5000
4800
4600
4400
4200
4000
40
COLLEGE OF MECHANICS & ENGINEERING


Points per Pound.
.900
.860
.820
.780
.740
.700
.660
.620
.580
.540
.500
40


Breaking Length in Metres.
6000
5800
5600
5400
5200
5000
4800
4600
4400
4200
4000
40
Ser.
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89085939122

b89085939122a

ch in per cent		Folds Number of double folds		
+	Average	—	+	Average